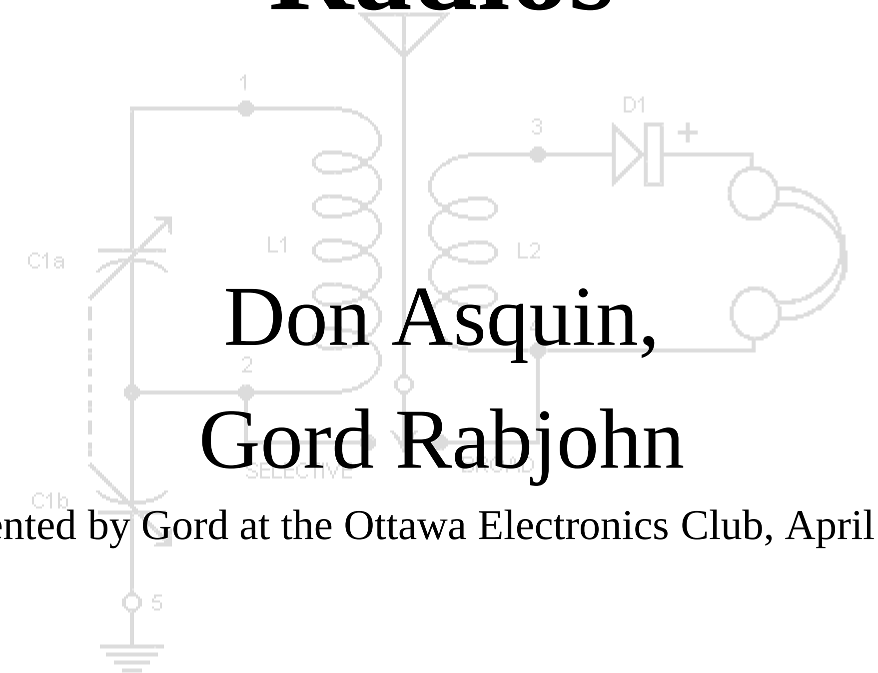
High Performance Crystal Radios



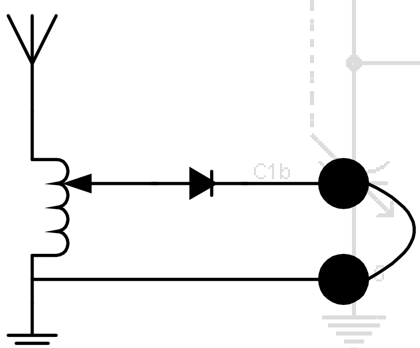
Don Asquin,

Gord Rabjohn

(Presented by Gord at the Ottawa Electronics Club, April 2012)

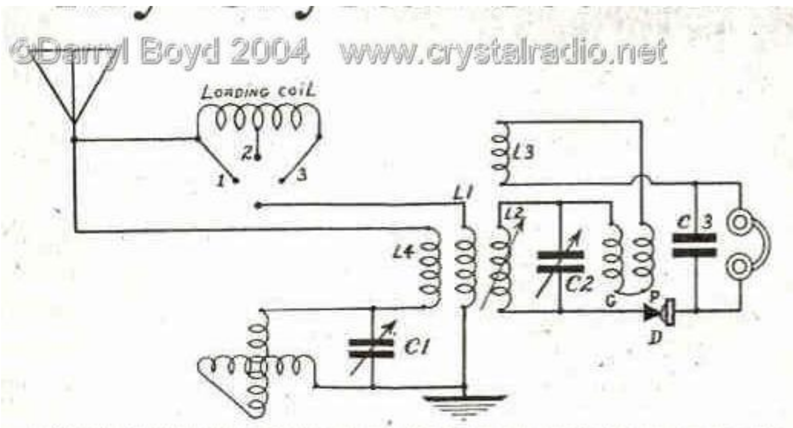
Childhood History

www.crystalradio.net



- Like many kids, I had frustrating childhood experiences with crystal radios!
- Simple crystal sets couldn't separate multiple AM radio stations.
- Only local stations were received, and everything was received all at once.

Rediscovering History



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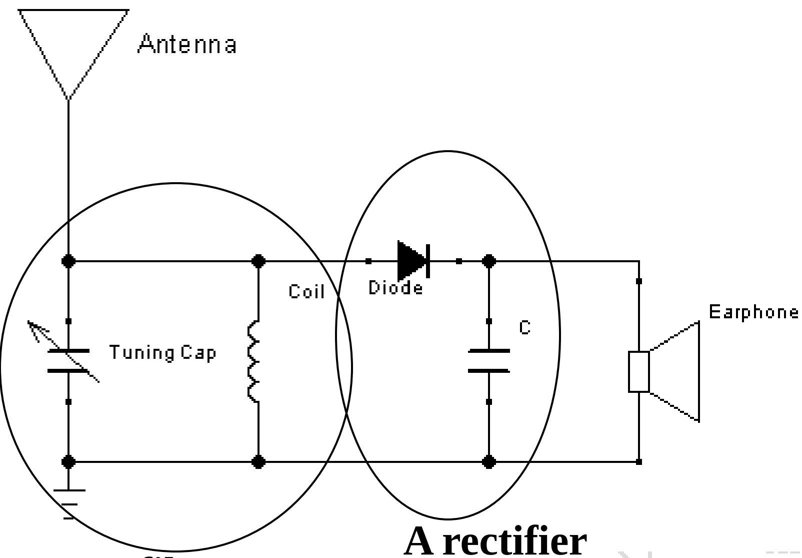
- Recently, my friend Don Asquin and I decided to build high performance crystal sets.
- Much of this exploration is rediscovering the knowledge of the 1910s and early 1920s.
- Even then there were claims of DX performance with crystal sets.

How does a basic crystal set work?



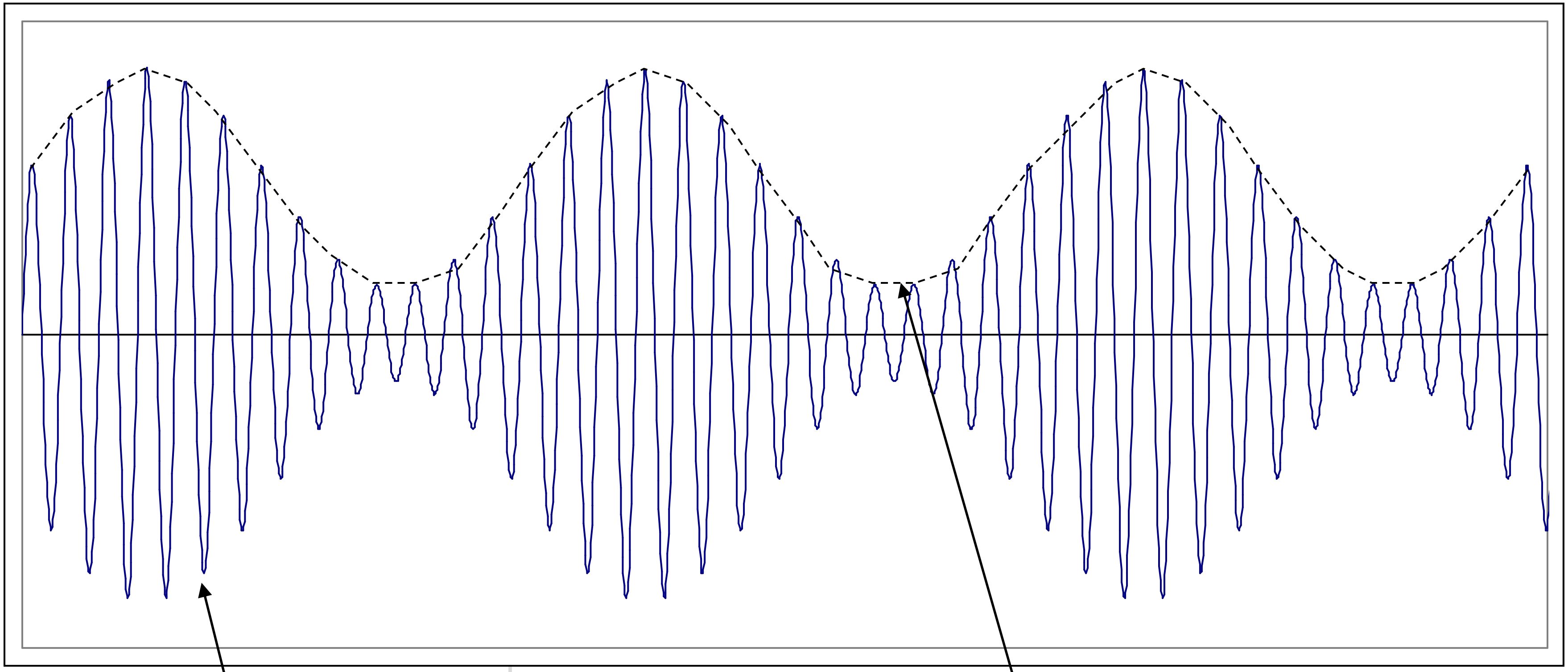
A rectifier

A filter

At low frequency, the inductor shorts the signal out. At high frequency the capacitor shorts the signal out. In-between, there is a magic point called "resonance"

- Antenna couples to the (usually) electric field in a radio wave.
- L-C selects the frequency.
- Diode rectifies it.
- Earphone makes it audible

AM modulated signal



RF Carrier frequency (say 1310kHz): the filter selects only this frequency.

Rectified audio output, smoothed by the capacitor

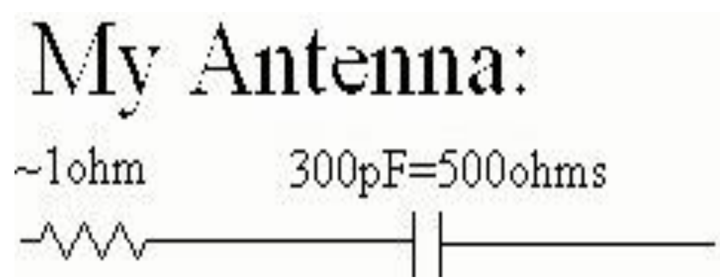
The Four Key Elements

www.crystalradio.net

- Antenna
  - Antenna
  - Ground
- Tuner
  - Loose coupler
  - High Q coils
  - RF impedance matching
- Detector
- Audio Transducer
  - Audio Impedance matching

Antenna

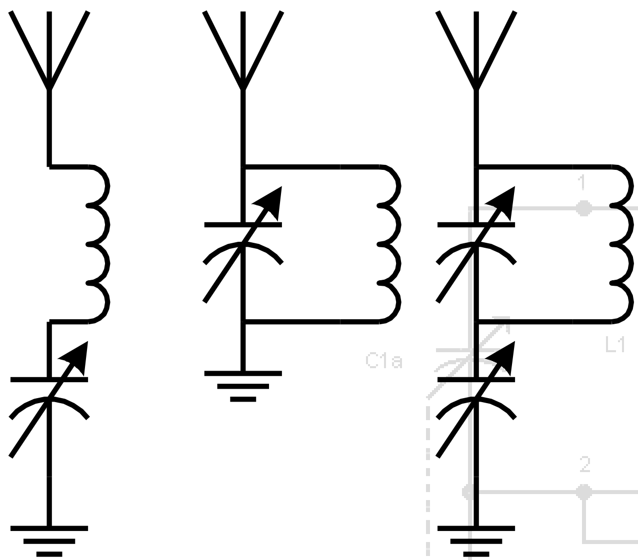
- A long exterior antenna is crucial.
- Why? It's not just about area… "watts per acre". It's also about giving the antenna a better "radiation impedance".
  - The energy from an antenna, can be modeled as a voltage source in series with a source resistance (or a current source in parallel with a source conductance), and the antenna capacitance (or inductance).
  - Radiation resistance is the resistance of this apparent source of energy in an antenna.
  - The tuned circuit matches this impedance to the load (detector) for optimum energy transfer.
  - A small antenna will tend to look like a "difficult to match" impedance….



Ground

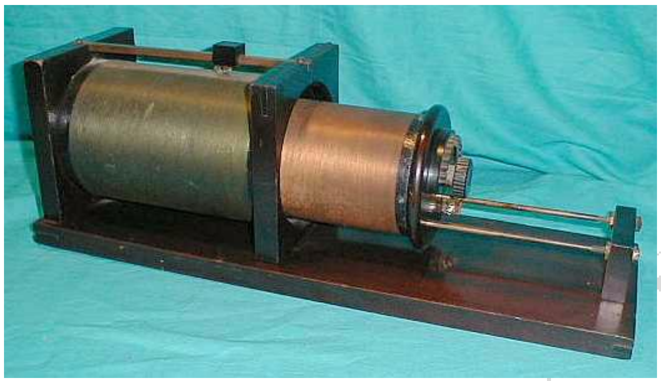
- The ground provides the completion of the current path for the radio signals.
- You can always attach a wire to a cold water pipe, but the best ground remains a copper plated rod pounded into the ground.
- Home Depot sells these rods for grounding electrical systems.
- If installed near a water tap, the ground can be kept moist and conductive.

Tuner
-Antenna Tuner



- To extract the most power, you need to match the resistance of the load (detector and earphone) to the impedance of the source (antenna)
- The function of the tuner is to match the radiation resistance of the antenna to the impedance of the detector, and to provide selectivity.

Tuner
-Loose Coupler



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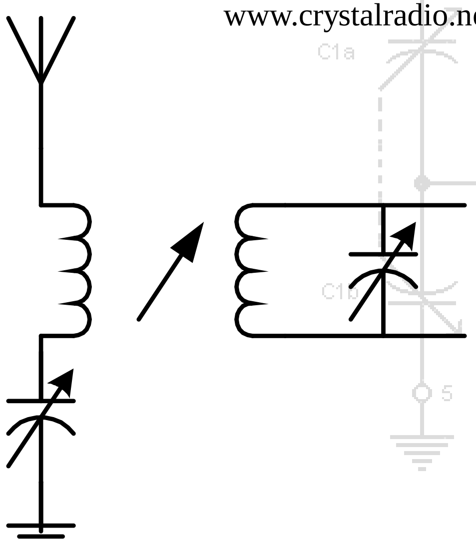
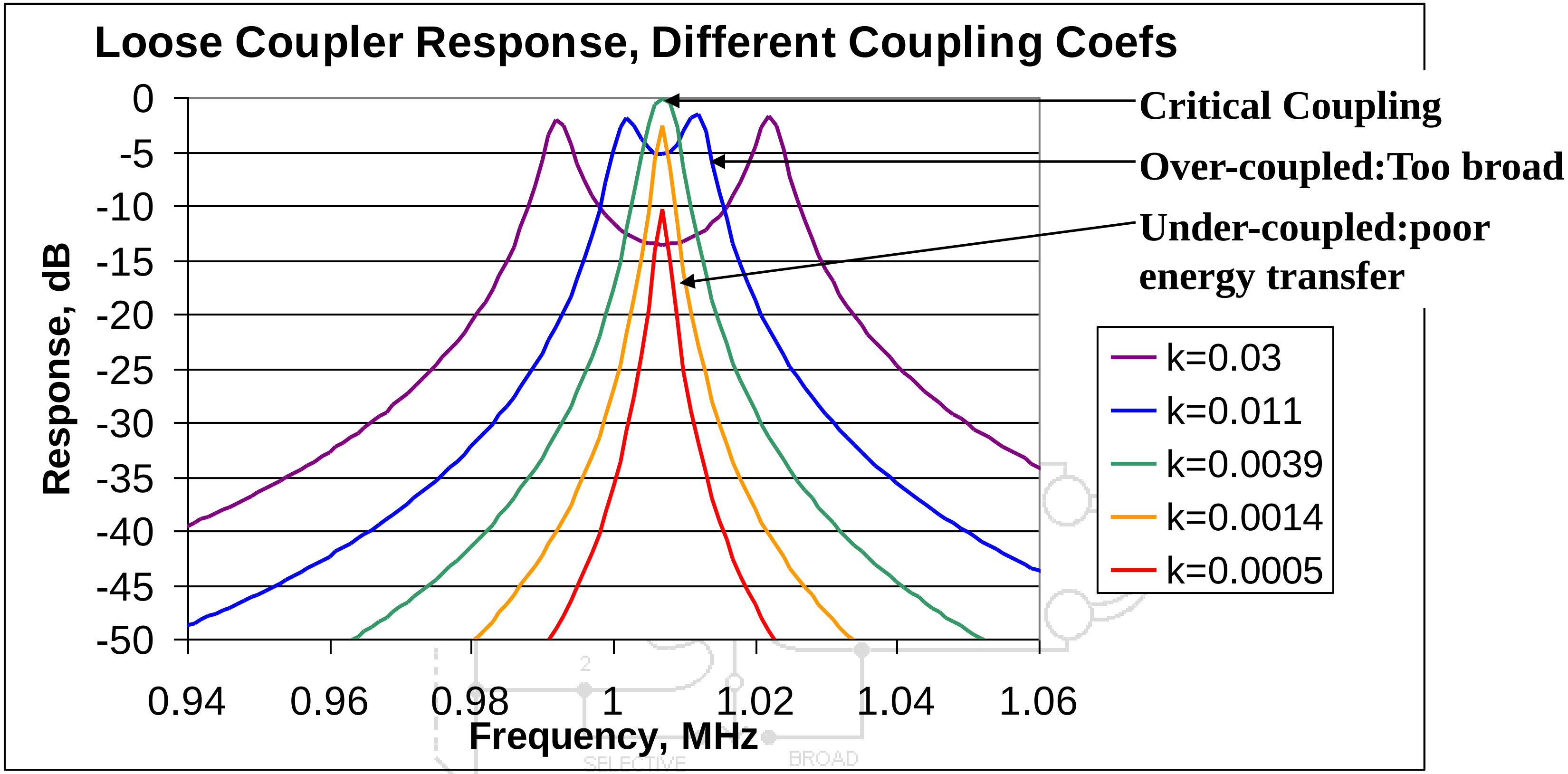


- The loose coupler is simply two coils (each generally resonated with a capacitor) lightly coupled to each other.
- One coil is connected to the antenna, the other is connected to the detector.
- Even cheap capacitors tend to be quite good, but high Q inductor fabrication is an “art”.

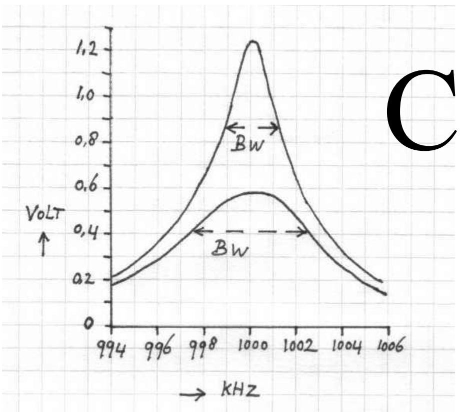
Loose Coupler



Simulation of 1000pF, 1.0 ohm antenna, 100uH primary coil and ~330pF cap, coupled to a 100uH secondary coil, 250pF cap, 100k load.

- There is an optimum amount of coupling between the coils. (=1/Q). This is VERY LIGHT coupling. Under 1% of the magnetic field is coupled.

Coil "Q" = Quality



www.crystal-radio.eu

$$Q = \frac{\text{Frequency}}{\text{Bandwidth}}$$

Station Frequency (kHz)	Minimum Q
540	54
1000	100
1600	160

Assume Q=160

Station Frequency (kHz)	Audio Bandwidth (kHz)
540	1.7
1000	3.1
1600	5.0

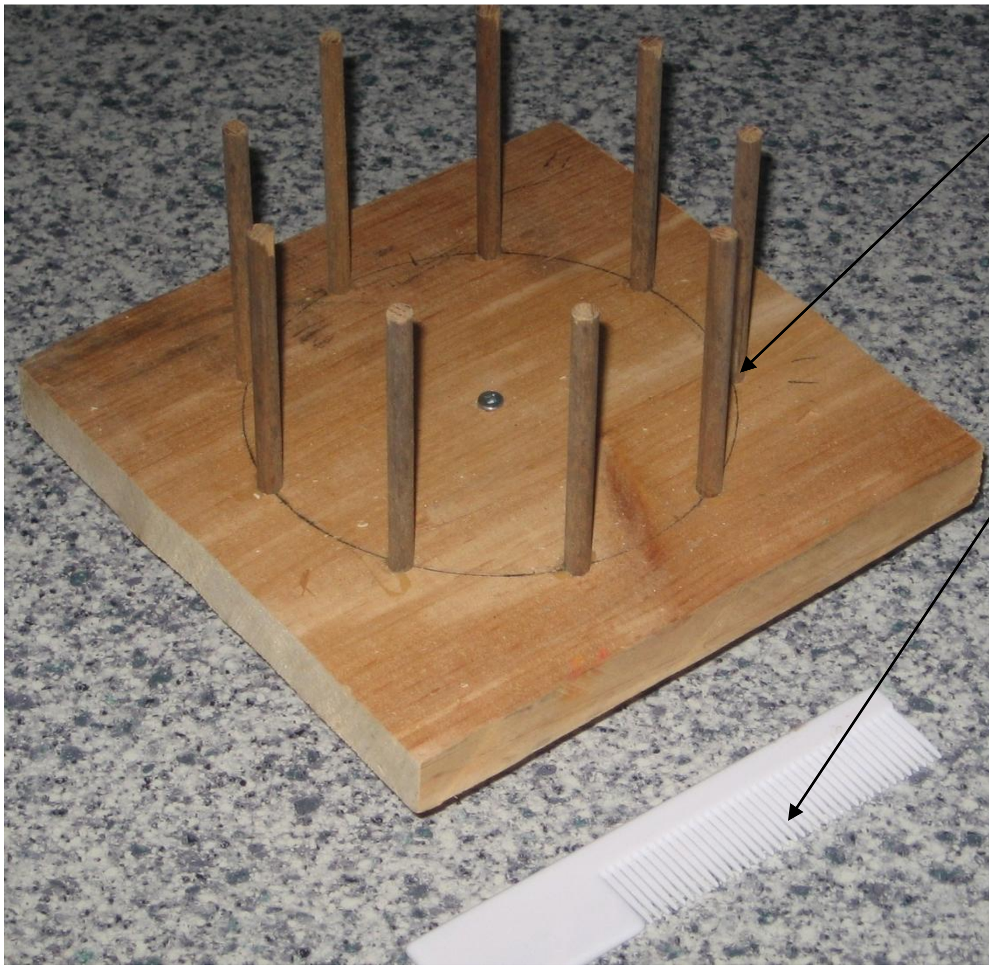
- For a tuned circuit "Q" is the ratio of the center frequency to the bandwidth.
- For a coil, it is the ratio of energy lost to energy stored.
- Q is very difficult to accurately measure.
- You can never have too much Q!
- The inductor is usually the part with the poorest "Q", so a lot of creative energy is invested into optimum devices.

Coil Types

www.wynterarchtops.com

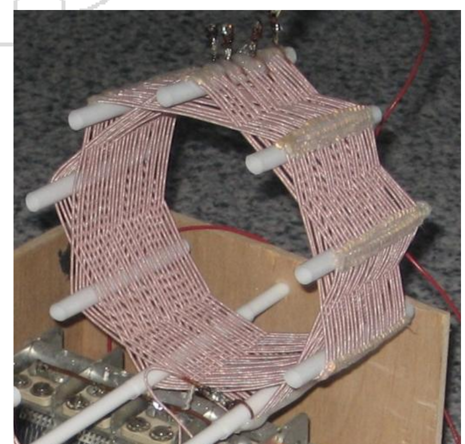
- The highest “Q” coils seem to be air core.
- Many different variations
  - Spider web,
  - Basket weave
  - Honey Comb
- All attempt to reduce capacitance and current crowding to increase Q

Coil Winding Jig

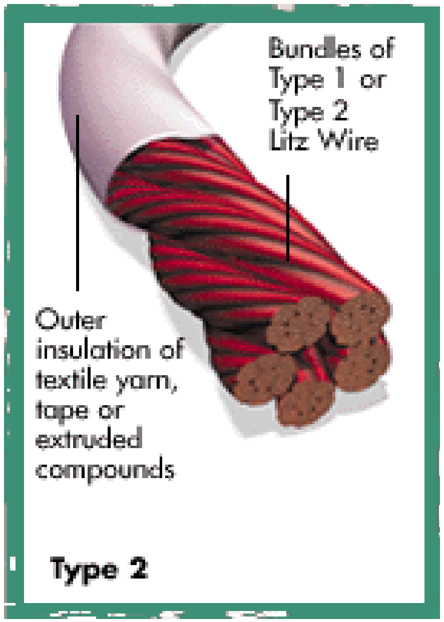


Drinking straws fit over ¼” dowels.

Comb helps space wires



Litz Wire



www.newenglandwire.com

- Best wire for high "Q" coils is Litz wire.
- Litz is derived from the German word "Litzendraht" meaning woven wire.
- Consists of many strands of parallel connected, individually insulated wire woven together in a regular pattern.
- Each wire alternates between the middle and the outside of the bundle.
- Each wire forced to carry about the same current, minimizing skin effect (the tendency for current to flow along the outside surface of a wire), and loss.
- The holy grail of litz wire is made up of 420 to 660 individual strands of 46 AWG wire all twisted together to make a 16-18 AWG wire.
- One comparison: A basket wound coil with solid copper wire (~200uH) has a Q of 230 at 1MHz. With Litz wire, it has a Q of over 500!

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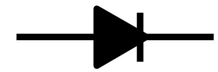
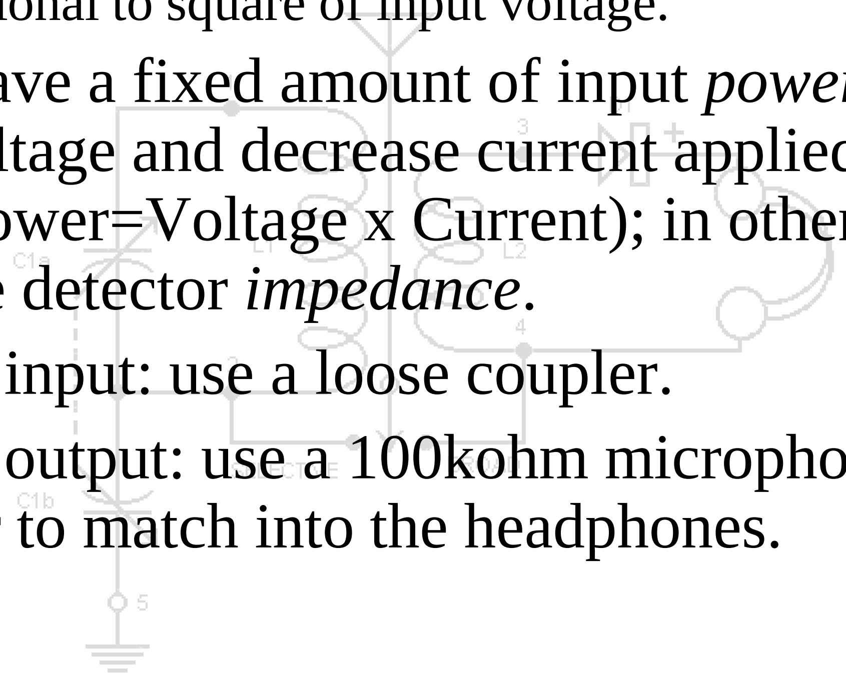
Detector



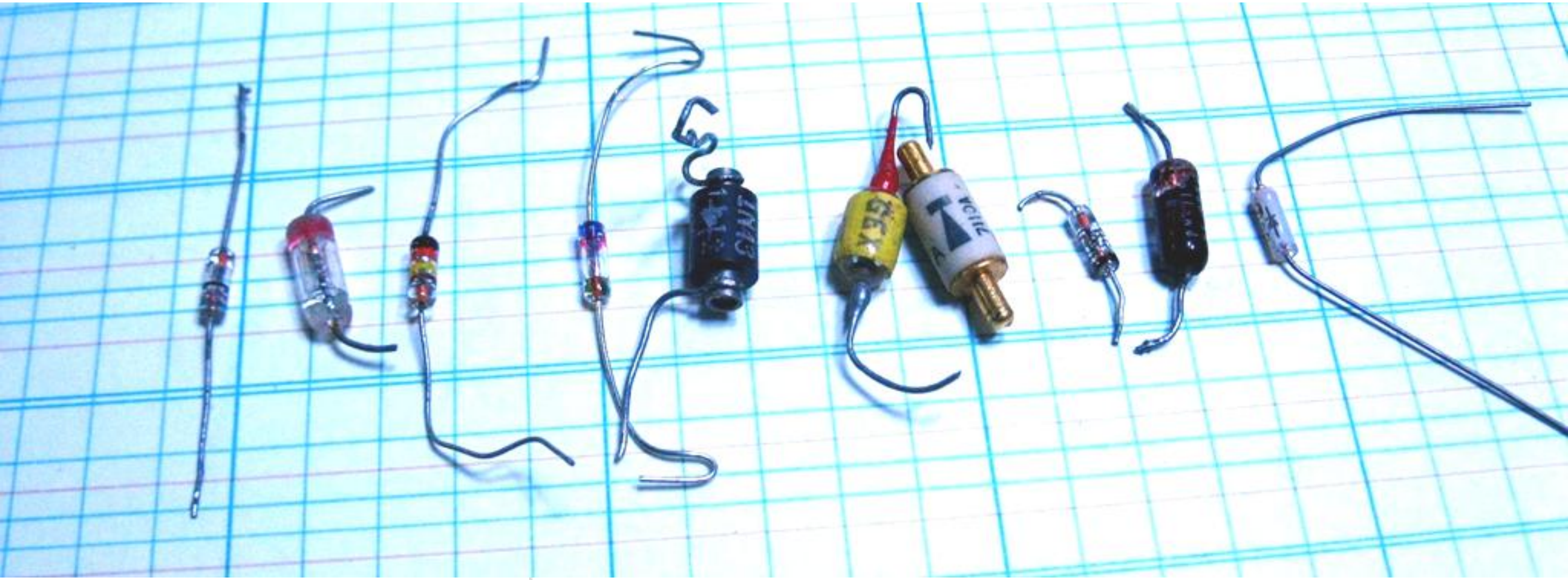
- In my experience, nothing beats a good 1N34A germanium diode. (Still widely available)
- Germanium is good because its barrier height (turn-on voltage) is lower than silicon, and a germanium diode is truly a point-contact diode (Schottky, not P-N diode), so has low charge storage (and therefore fast switching times).
- Specified with very low capacitance, less than 1.0pF.
- Main complaint about 1N34A diodes is that they tend to have high and highly variable leakage.
- Best solution is to try several, doing A B comparisons and select the best germanium diode in your drawer .

Detector Impedance

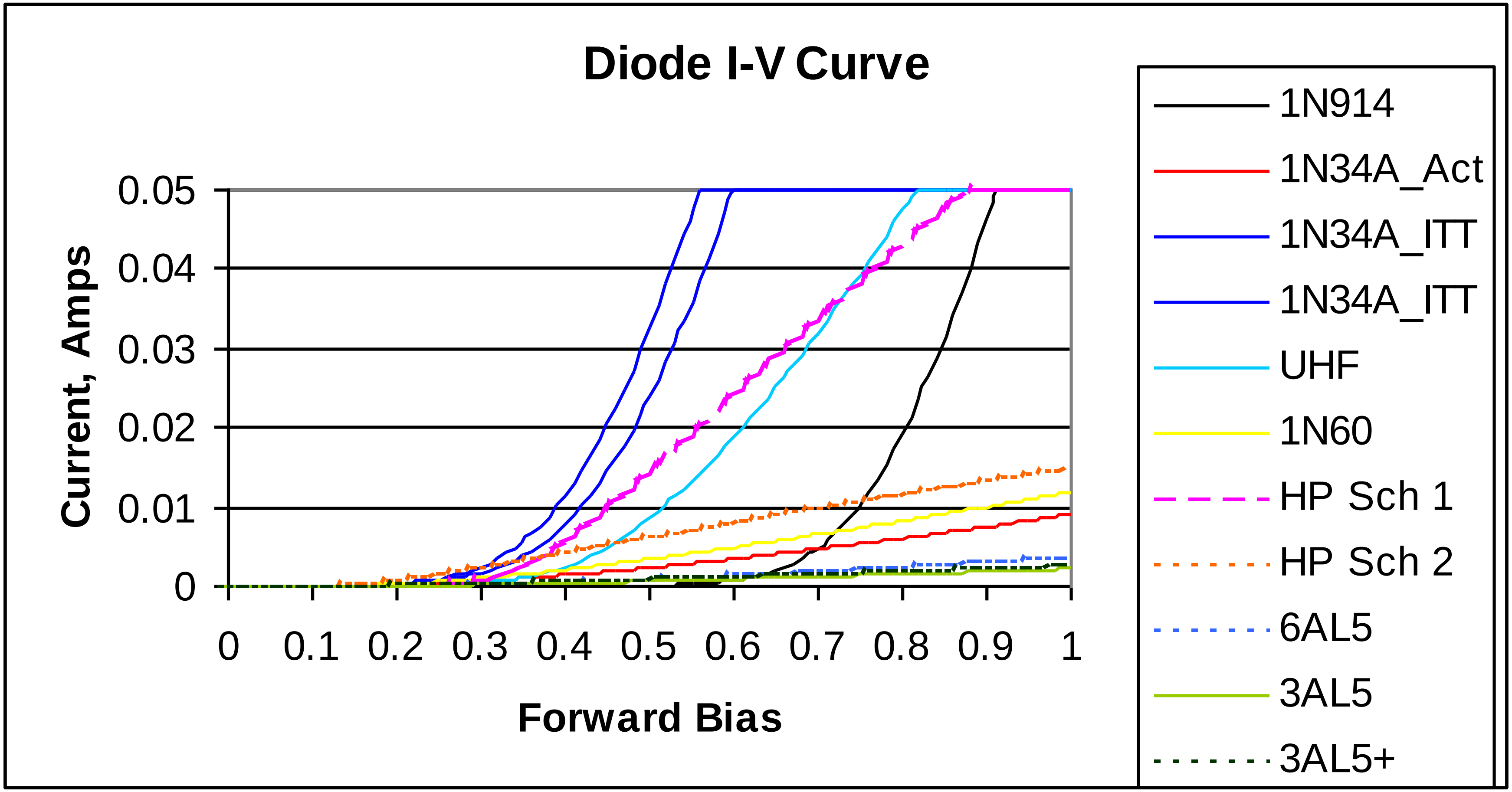
- Detectors are most efficient when driven with *high voltages*.
  - Detectors are "square law" devices (at low power), output voltage is proportional to square of input voltage.
- Since we have a fixed amount of input *power*, we need to increase voltage and decrease current applied to the detector (Power=Voltage x Current); in other words increase the detector *impedance*.
- At detector input: use a loose coupler.
- At detector output: use a 100kohm microphone transformer to match into the headphones.



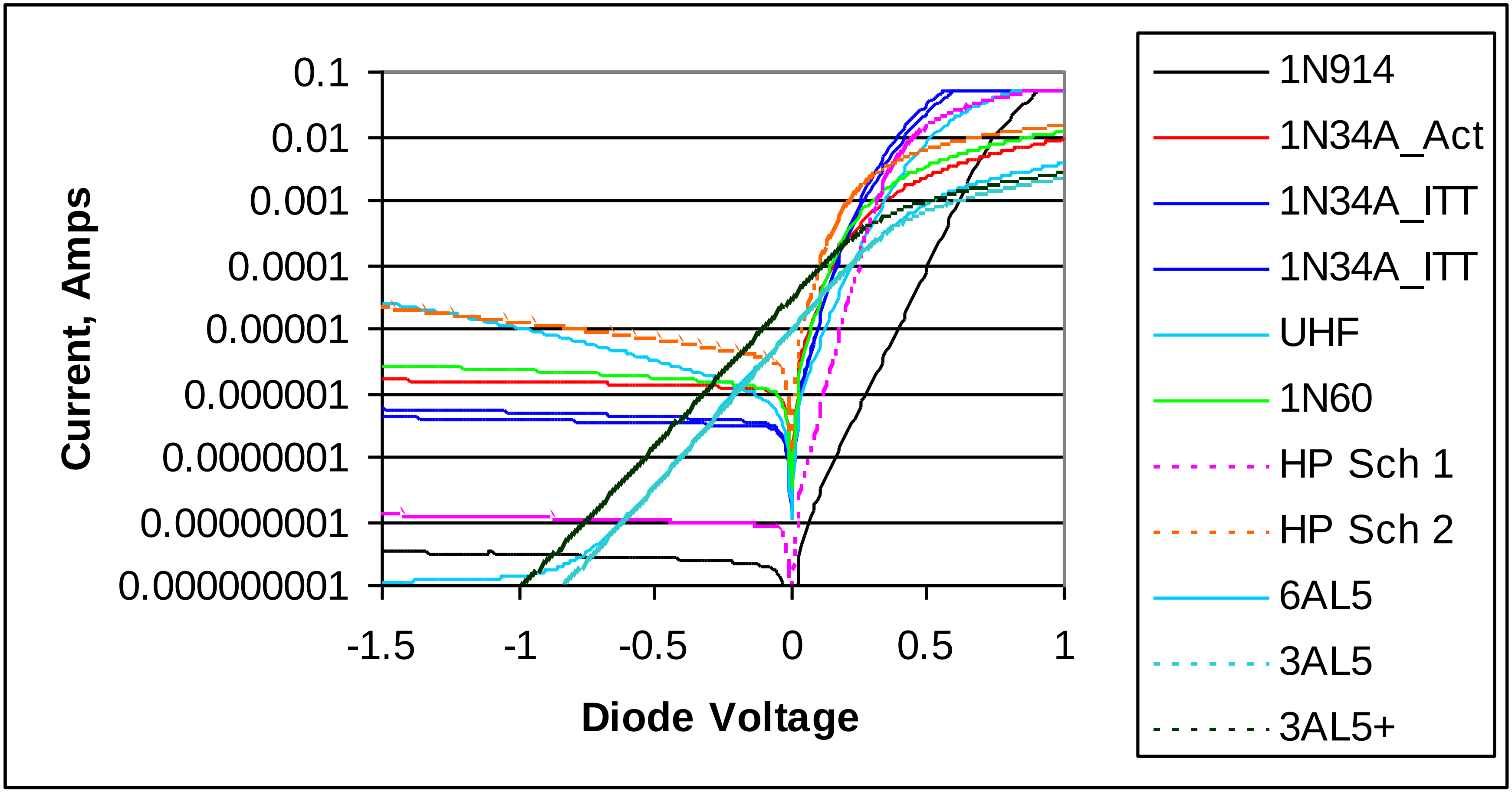
Germanium Diodes



Detectors: I-V Curves

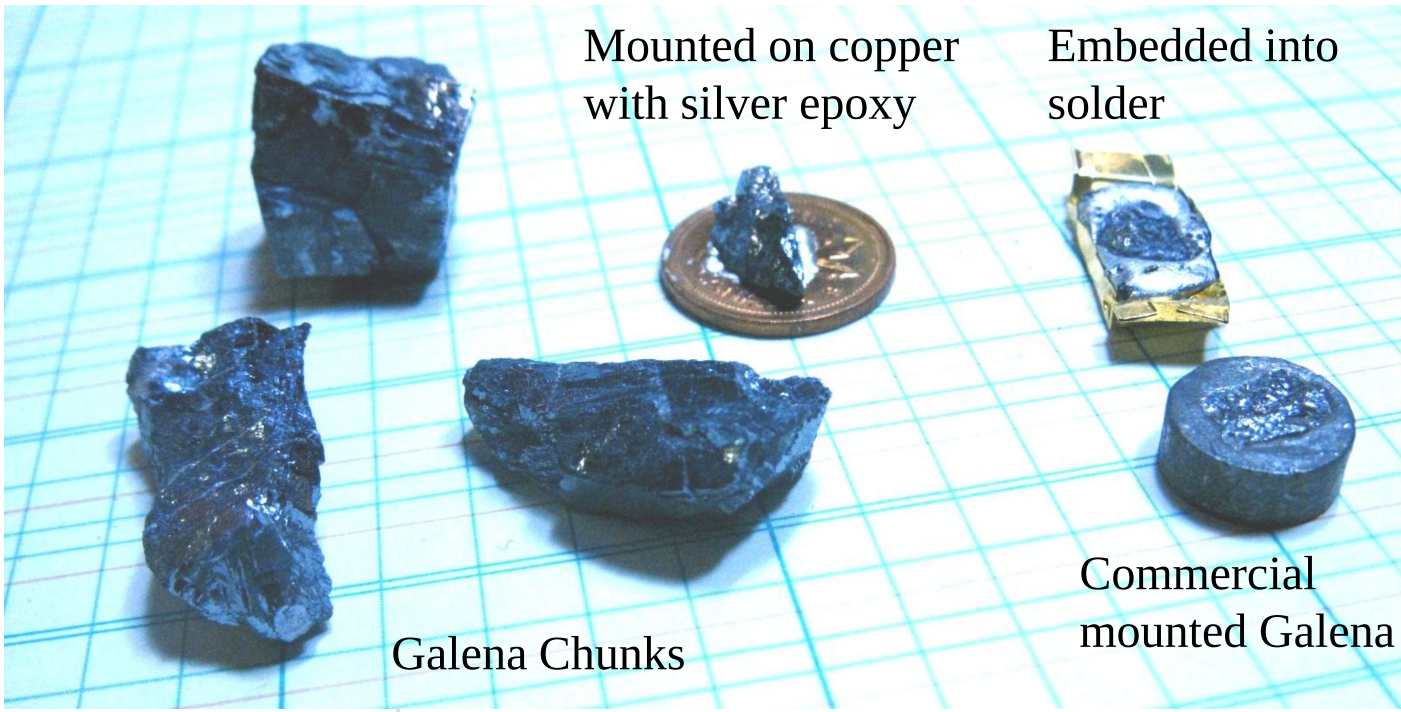


Detectors: I-V Curves

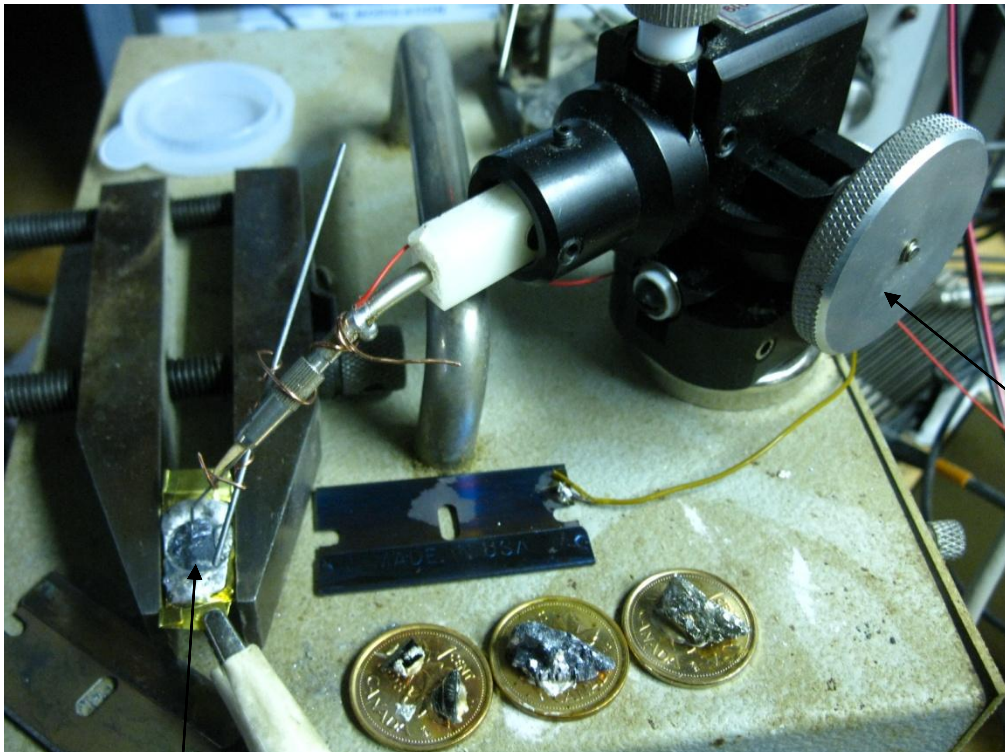


Mineral Detectors

Lead Sulfide, PbS (Galena), Iron Pyrite, Zincite, and other minerals have been used to make detectors (surprisingly good).



Galena Detector



X-Y-Z manipulator

Galena mounted in solder

Audio Transducer

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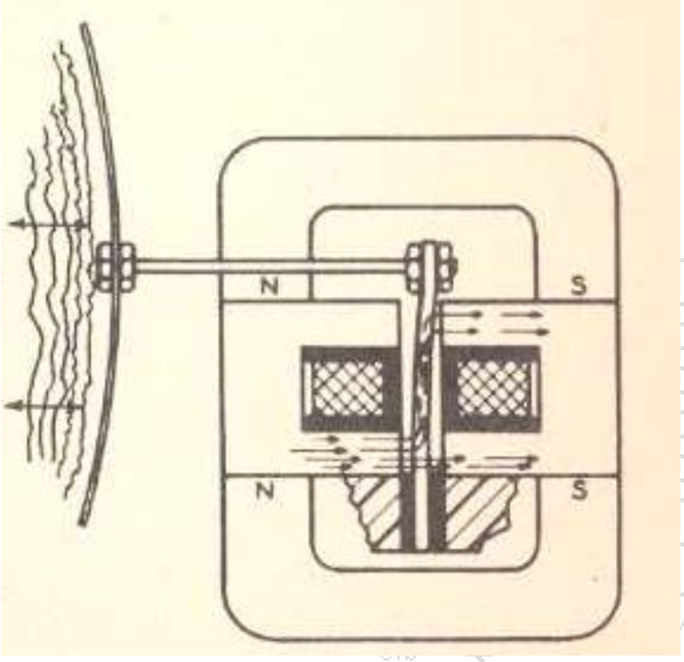
- Best transducers (headphones) for crystal radio operation are “Sound Powered” headphones or “Deck Talkers”.
- Developed in WWII for the navy to allow communications between the observers and gunners without the need for external power source.
- So sensitive that the pressure of the talkers voice in the microphone is sufficient to drive the headphones of the listener.

Audio Transducer



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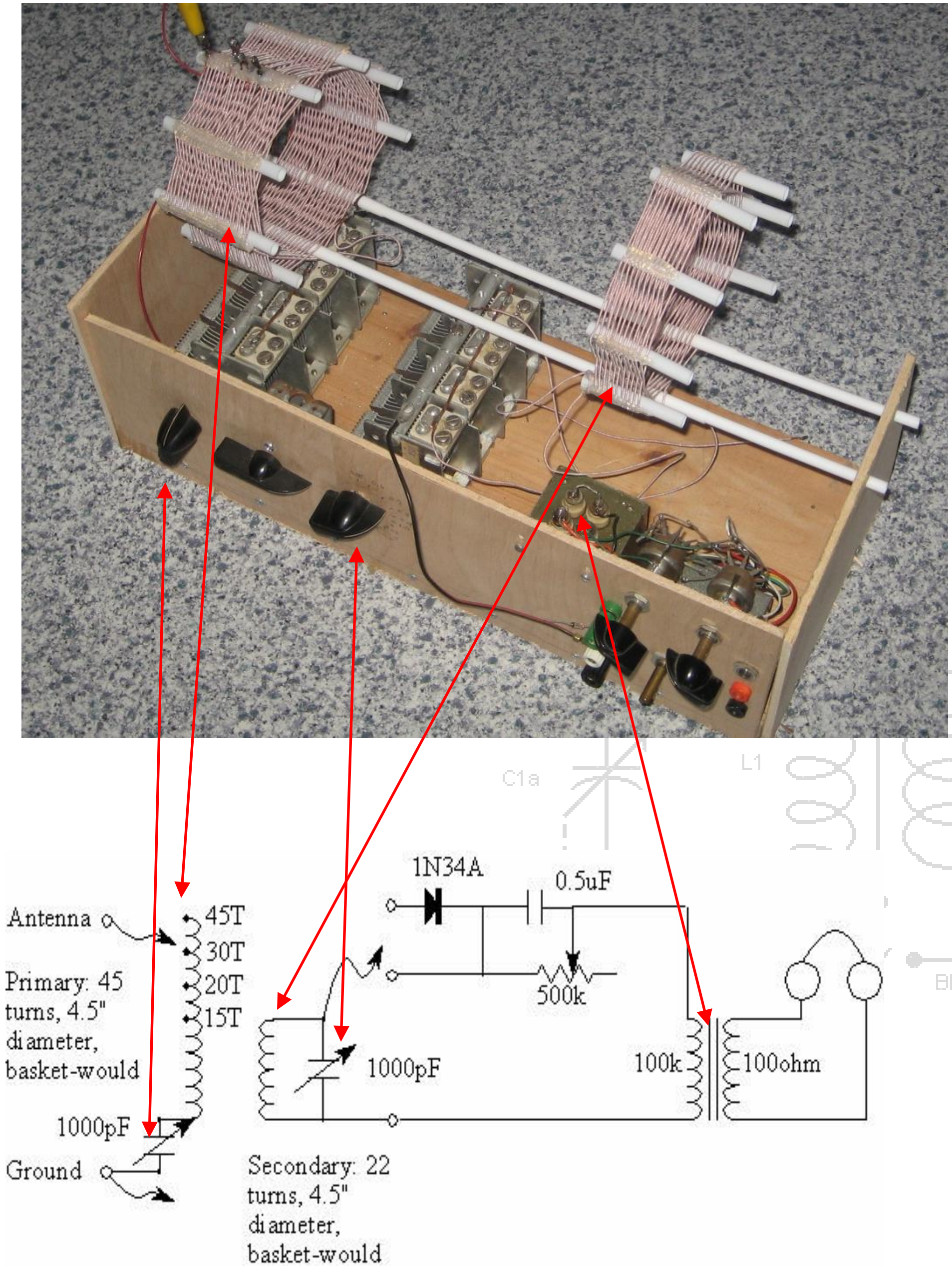
- An elaborate mechanism balanced armature system) give the sound powered headphones their sensitivity.
- Impedance typically around 1000 ohms, much too low for direct use in a crystal set. An impedance matching transformer is essential.
- Microphone transformers are excellent choices for matching the impedance of the diode to the headphones.

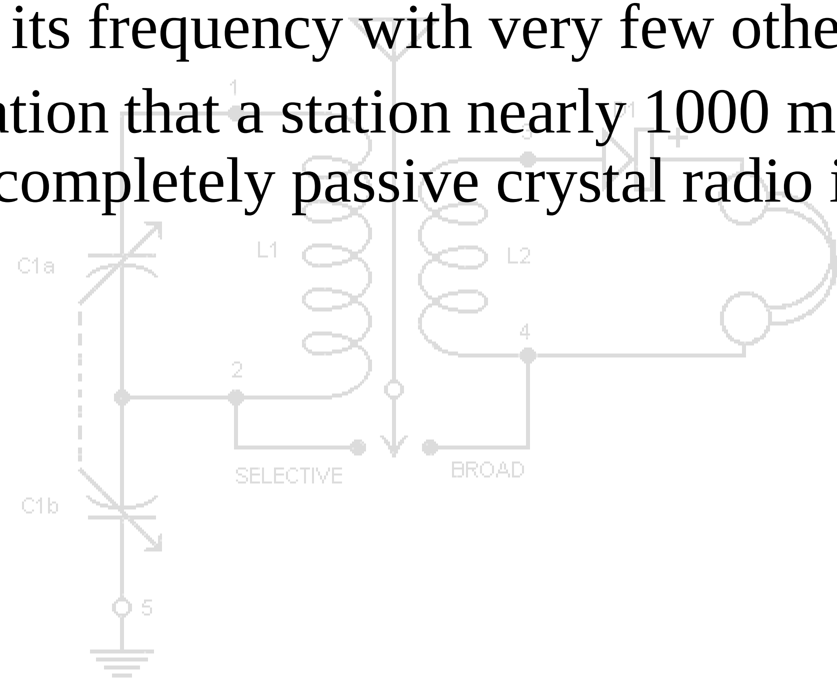
Final Results



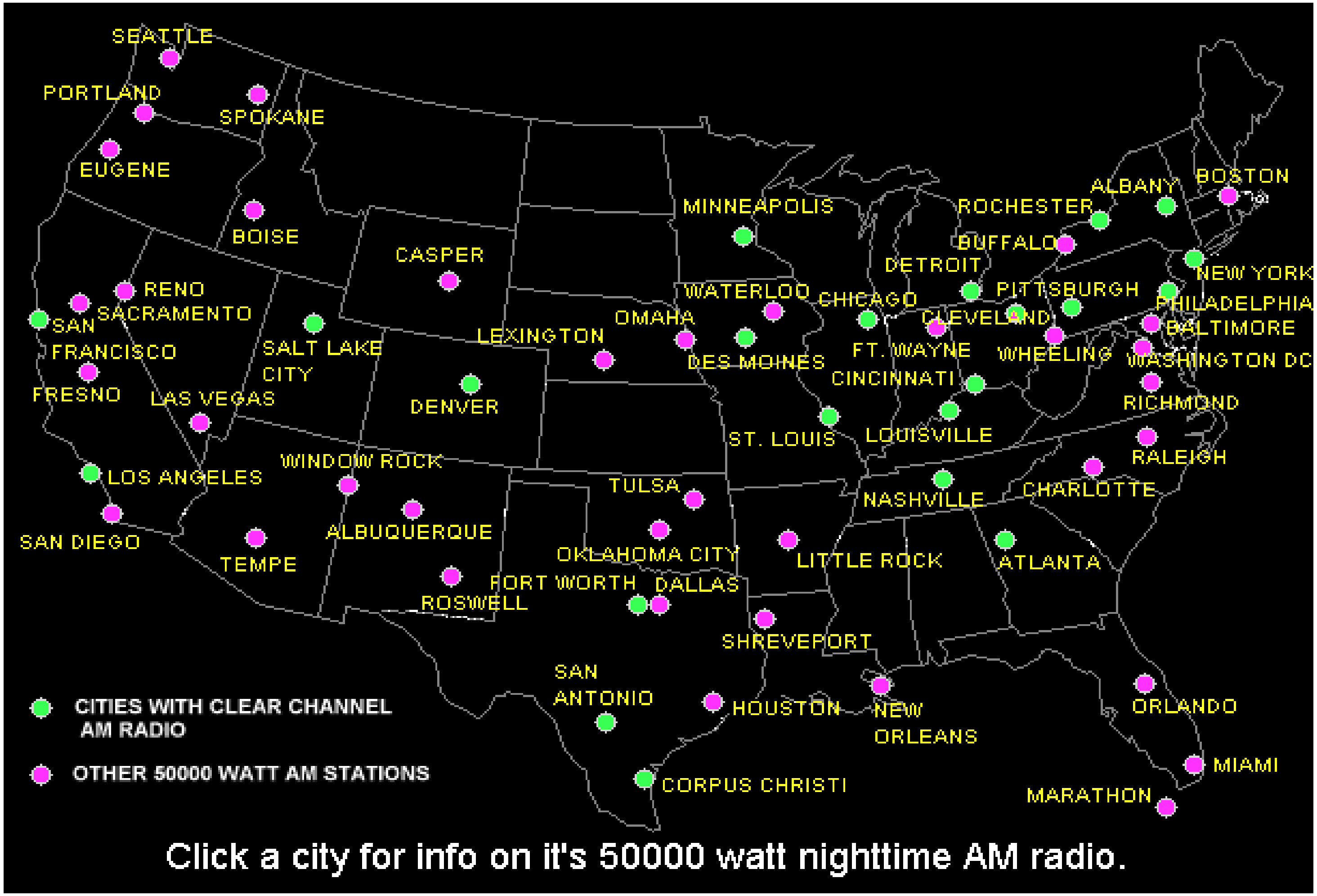
- Litz wire basket wound with taps for experimentation.
- Series antenna tuner above 650kHz. Below 650kHz, capacitor has to be placed in parallel with the inductor
- Ceramic insulated variable capacitors for maximum Q
- R-C allows DC to build up, reduces detector loading and reduces distortion on local stations.

Clear Channel Stations

- Most of the distant stations we receive are 50,000 Watt "clear channel" stations.
- A clear channel station is a high power American station that shares its frequency with very few other stations
- The realization that a station nearly 1000 miles away can be heard in a completely passive crystal radio is amazing



Clear Channel Stations

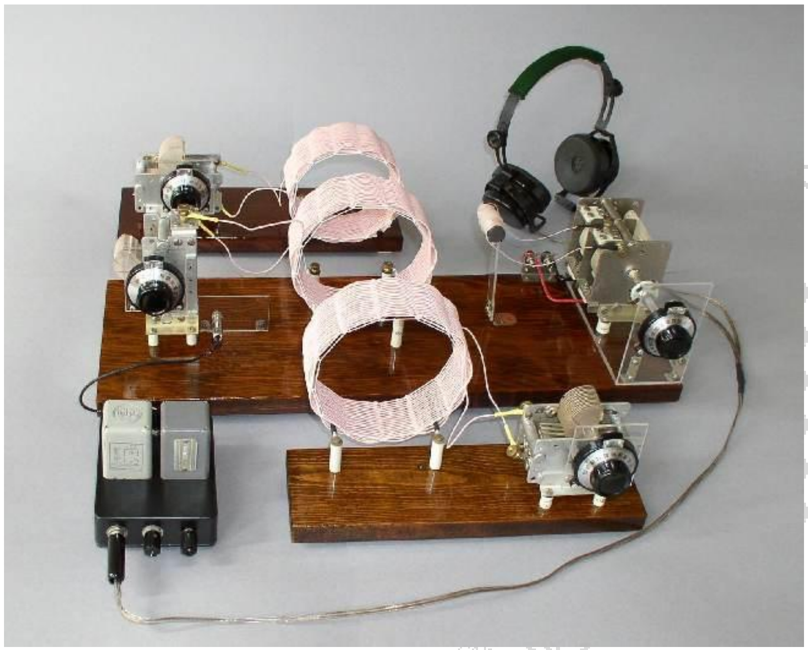


- http://www.fortunecity.com/tinpan/bluenote/706/namrp/amradio.htm#anchor3

Stations Logged

- 640 CFYI, Toronto
- 660 WFAN, New York City
- 680 CFTR, Toronto
- 690, Montreal
- 700 WLW, Cincinati
- 720 WGN, Chicago
- 740, Toronto
- 760 WJR, Detroit
- 770 WABC, New York City
- 780 WBBM, Chicago
- 800 CJAD, Montreal
- 810 WGY, Schenectady
- 840 WHAS, Louisville
- 880 WCBS, New York City
- 920 WHJJ, Providence
- 940 CINW, Montreal
- 990 The Team, Montreal
- 1000 WMVP, Chicago
- 1010 CFRB, Toronto
- 1020 KDKA Pittsburgh
- 1030 WBZ, Boston
- 1060 KYW, Philadelphia
- 1080 WTIC, Hartford
- 1500 WTOP Washington
- 1520 WWKB, Buffalo
- 1560 WQEW, New York Citiy

Top Performers



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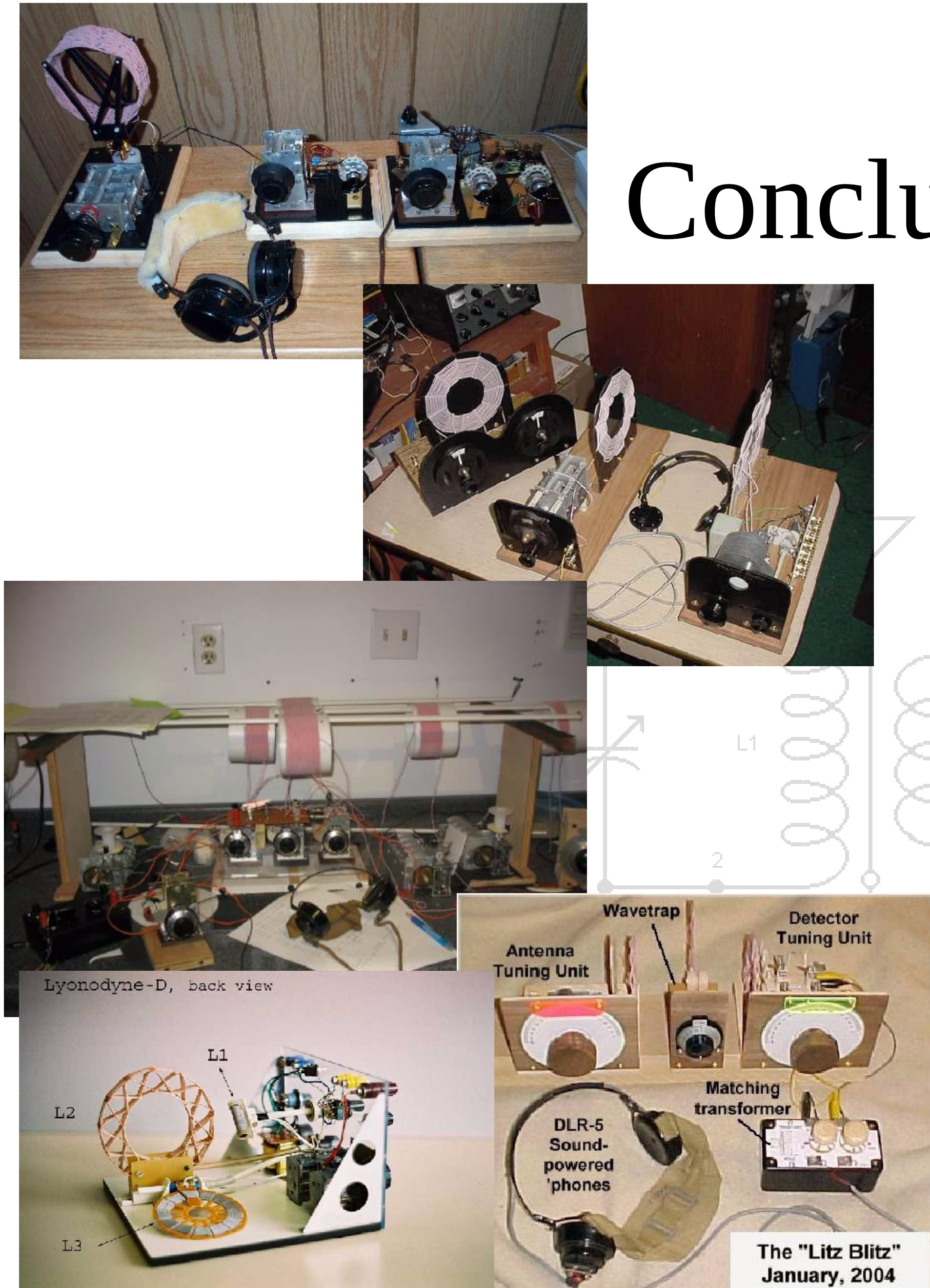
- Mike Tuggle of Hawaii is one of the top builders of crystal sets.
- His set, the Lyonodyne-17 has heard stations in Cuba from his home location in Hawaii!
- There are lots of web resources available. This presentation describes my efforts.

Conclusions



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- Crystal sets appear to be simple, but attention must be paid to all the details.
- If you truly understand a crystal radio, you have a good foundation to RF engineering in general.